



Working Memory Assessments: Going Beyond Auditory and Visual Representations, to Include Sub-Skill Processes

Citation

Mascio, Bryan. 2017. Working Memory Assessments: Going Beyond Auditory and Visual Representations, to Include Sub-Skill Processes. Qualifying Paper, Harvard Graduate School of Education.

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**Working Memory Assessments: Going Beyond Auditory and Visual
Representations, to Include Sub-Skill Processes**

Qualifying Paper

**Submitted by
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December, 2015

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Introduction

Working memory is an important skill necessary for many aspects of our lives. In education, it is often employed as assessment for predicting academic performances, such as reading and math, as well as behavioral problems (Alloway, Gathercole, Kirkwood, & Elliott, 2009; Kane et al., 2004). Within research, it is used to better understand human potential and limitations ranging from those with learning disabilities (Alloway, 2007) to populations with specialized skills such as ballet dancers (Bläsing, 2010) or simultaneous interpreters (Christoffels, de Groot, Annette M. B., & Kroll, 2006).

While the concept of working memory (WM) evolved from the study of short-term memory (STM), working memory is understood as something more – it is the combination of storage and manipulation of information (Baddeley, 2010).

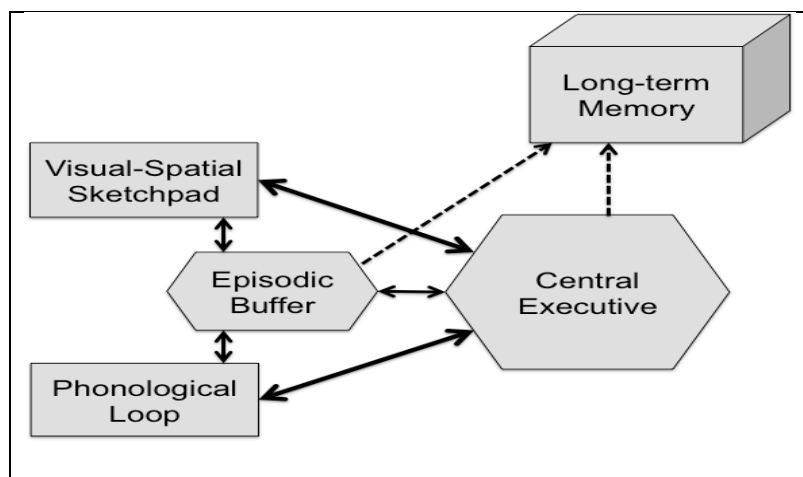


Figure 1. Components of working memory, their relationship with each other and long-term memory – based on Baddeley's (2012) model

In education and psychology, the most influential model of WM, Baddeley's model (see Figure 1), has four components: Phonological loop,

visual-spatial sketchpad, episodic buffer, and central executive (Baddeley, 2012).

The phonological loop stores auditory short-term memory through subvocalized rehearsal – extending its use beyond auditory stimuli to written material, lip reading and signing. The visuo-spatial sketch-pad is used for visual STM and stores visual-spatial stimuli – its means of rehearsal are unclear. The episodic buffer is a relatively new addition to this model that holds multi-dimensional information that will interact with the other three components as well as long-term memory – essentially, it combines incoming information and adds a sense of time, making sense of the pieces of information. (Baddeley, 2012) The fourth component, central executive, manages the two STM systems as well as episodic buffer by managing attention and interacting with the separate system of long-term memory. It is the central executive functions that are most commonly referenced when the term Working Memory is used (Kane et al., 2004).

Based on the influence of Baddeley's model, it is understandable that the most common categorizations in working memory assessments used in schools and clinical settings are auditory and visual (sometimes replaced with verbal and non-verbal, respectively). Especially since Baddeley's original model only included the two "slave systems" of the phonological loop and the visual-spatial sketchpad, it logically followed that assessments should target each of the two modalities that they stored – the auditory and visual. Remnants of this two-category thinking can still be found in such assessments as the Children's Memory Scale (Cohen, 2015), Automated Working Memory Assessment (Alloway,

Gathercole, & Pickering, 2006), Wechsler Memory Scale – Fourth Edition (Wechsler, 2009), and the Wide Range Assessment of Memory and Learning – Second Edition (Sheslow & Adams, 2015).

Outside of school assessment, however, researchers in experimental psychology and neuroscience have discovered and utilized other ways of categorizing working memory. These have included a focus on functionality or sub-skills, processes beyond the modalities of auditory and visual. This alternative focus does not contradict Baddeley's model, but can rather be seen to incorporate the more recent third “slave system”, episodic buffer. Applying this sub-skill categorization can change how we interpret working memory assessments.

For example, in the Wechsler Memory Scale – Fourth Edition (Wechsler, 2009), the Visual Working Memory Index is comprised of two subtests – the Spatial Addition test, and Symbol Span test. The former requires holding and manipulating visual-spatial information, while the latter requires recalling and selecting designs in the correct sequence. With the current focus on modality, these two tasks are combined because of their utilization of visual information – even if there were a large discrepancy between them, the scores would be averaged together to create a composite ‘Visual WM’ score. However, a focus on sub-skill would lead us to see that a low score on the Symbol Span test may actually reveal a problem with sequencing, itself – especially if it were accompanied with a low score on an auditory sequencing task. Averaging this low

Symbol Span score with a higher Spatial Addition score would potentially mask the student's underlying difficulty with sequencing.

Incorporating the findings of other areas of research that focus on sub-skills may enhance our utilization of current assessments. Within each modality of auditory and visual, it is common to divide the tasks into short-term (or immediate) memory, and working (or delayed) memory. Short-term memory tasks typically have little or no delay between the presentation of stimuli and the opportunity to produce or identify a correct answer – the answer being precisely the same as the original stimuli. Working memory tasks commonly include a delay in response and/or some intellectual work required to produce a correct answer.

Short Term Memory → Immediate Recall and Sequencing Tasks

Many of the tasks that are referred to as STM actually include a combination of immediate recall and sequencing skills. An example of this would be the forward digit span for auditory stimuli and the forward Corsi block task for visual stimuli. These tasks require recall of numerals presented orally, or positions selected on a board, in the correct sequence – correct responses given out of sequence are scored as errors. These tasks are typically considered to be simple span tasks, indicative of STM, but there is reason to believe that the inherent sequencing aspect of the tasks confounds them.

Psychology researchers specifically developed the Visual Patterns Test in order to test visual-spatial STM because the Corsi block task does not distinguish between STM and sequencing (Della Sala, Gray, Baddeley, Allamano, & Wilson, 1999). The Visual Patterns Test presents “checkerboard patterns” of increasing complexity and asks participants to recreate them by filling in the correct squares on a blank grid of the same size. Weak correlations with the Corsi task, and the Visual Patterns Test’s superior ability to differentiate between functioning of brain-injured patients, led Della Sala et al. (1999) to conclude that the visual STM is actually comprised of a visual STM and a spatial-sequential STM. Furthermore, using single-cell neural recordings in monkeys, Ninokura, Mushiake, and Tanji (2004) have demonstrated that distinct activity was observed in the lateral prefrontal cortex in response to order and object recognition. These researchers concluded that the neural process supporting working memory is influenced by temporal order of representations. In an additional series of non-human primate studies examining prefrontal cortex activation, a distinction was found between spatial memory and the sequencing of events (Ashe, Lungu, Basford, & Lu, 2006).

Working Memory → Suppression of Interference and Manipulation Tasks

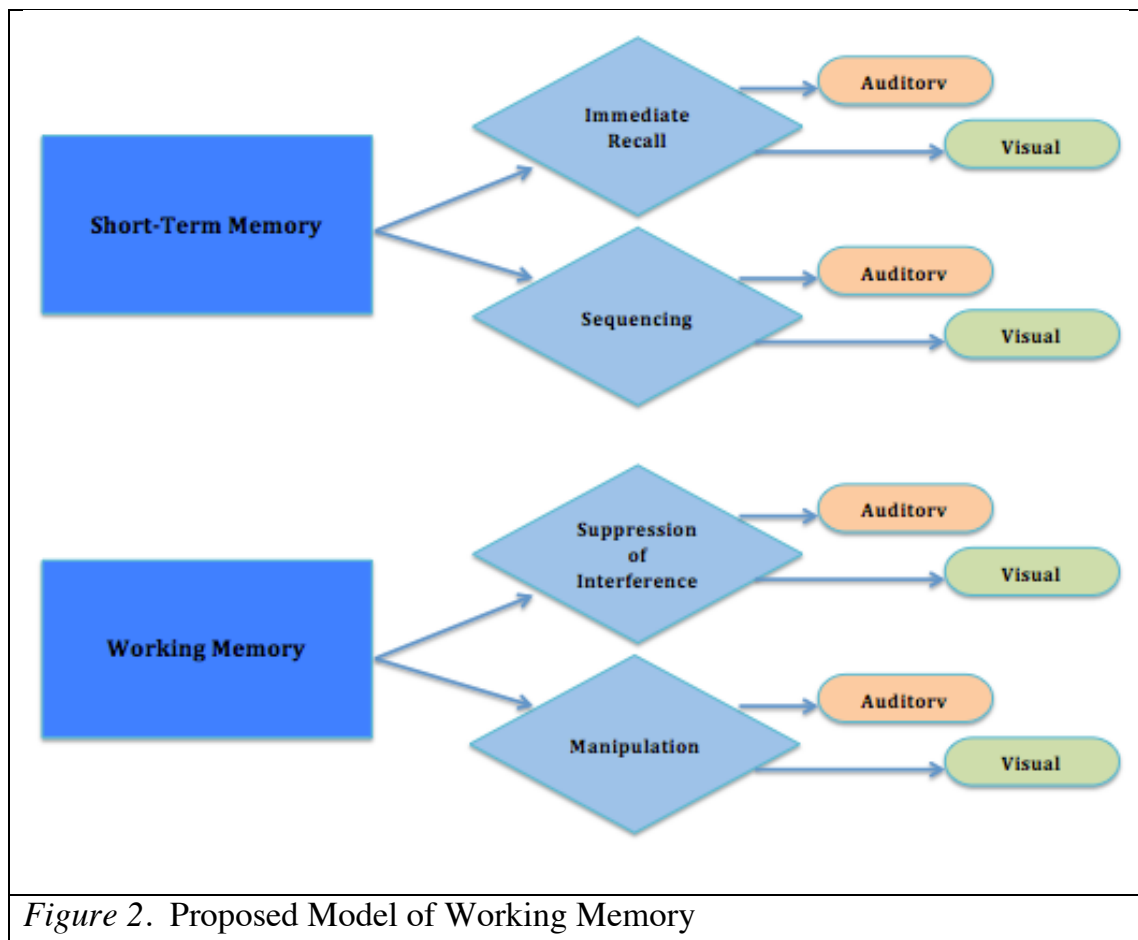
Within WM, I propose a differentiation between Suppression of Interference (SoI) tasks and manipulation tasks. SoI tasks are those that interleave the memory task with some sort of distractor, either between each part of the

stimuli or at the end of each trial before the response. A manipulation task, however, is when the stimuli itself must be mentally manipulated. Most complex span tasks are examples of SoI tasks – operation span (Turner & Engle, 1989) has math problems distract from memorizing words or letters, and the reading span (Daneman & Carpenter, 1980) has semantic meaning interfere with memorizing words or letters. Examples of manipulation tasks would be the alpha span task where participants hear a mix of words and must recall them in alphabetical order, the letter number sequencing task where a student hears a mix of letters and numbers and must recall them separately in alphabetical and numerical order, or the backward digit span task that requires students to recall numbers in the reverse order that they were heard.

When Cutting et al. (2009) used the backward digit span (a manipulation task) as a measure of auditory WM in a battery of assessments, typical and struggling readers did not show differential performance. This was the only one of the tasks that did not show the differentiation, and is in direct contrast with complex span tasks' (an SoI task) typical correlation with reading ability (Cutting et al., 2009) – suggesting an important distinction between SoI and manipulation tasks. Conway (2005) explains that there are conflicting findings of whether SoI and manipulation tasks are testing different skills. While some studies have shown the backward digit span as grouping more with STM than WM (suggesting that it is different than the SoI tasks that comprised the WM), others have shown

correlations between SoI and manipulation tasks – ultimately, they call for the need to have future clarifying studies.

Embracing the research findings that focus on sub-skills, I propose a new framework for conceptualizing working memory tasks, primarily for the purpose of academic assessments. Four hypothesized sub-skills (immediate recall, sequencing, SoI, and manipulation) are the common processes that are required to process information in each of two modalities (auditory and visual). More specifically, STM can be divided into tasks measuring immediate recall and



sequencing, and WM can be divided into tasks that measure SoI and manipulation (see Figure 2). By differentiating these related but separate processes, educators will better understand the unique abilities and challenges of their students.

The Present Study

I wished to investigate the relationship between the two modalities of STM and WM (auditory and visual) and the hypothesized sub-skills within each (Immediate Recall, Sequencing, SoI, and Manipulation). In order to do this, I designed eight computer-based tasks - one auditory and one visual, for each of these four sub-skills. Our analysis specifically looked at correlations between the tasks. Aligned with the current assessment paradigm, I anticipated strong correlations within each modality (ex. Auditory Immediate recall with Auditory SoI and Auditory Sequencing). However, I also hypothesized finding strong correlations within a sub-skill (ex. Auditory Sequencing and Visual Sequencing), supporting the possibility of a domain-general sub-skill and corroborating the potential value of my proposed framework.

Acknowledgements

This study was developed as part of the course, H-140 Seminar on Experimental Research in Psychology and Cognitive Neuroscience. As such, I benefitted from the input and feedback of various classmates. The course was taught by my advisor, Gigi Luk, who also provided invaluable feedback and

guidance. Dr. Luk also provided support through use of her laboratory space and resources – including financial compensation for participants. Additionally, Sibylla Guerrero – initially as a research assistant in Dr. Luk’s lab, and then later as a doctoral student – assisted in cleaning and compiling the raw data from participants, and then performed some of the statistical analysis reported in the Results section.

Methods

Task Development and Descriptions

Visual tasks. On a PowerPoint slide, I created an eight-by-eight table the full size of the slide, filled with an off-white color. Between three and six of the cells were filled with a bright red color. These red “blocks” were located by identifying each cell with sequential numbers from one through sixty-four, and then randomly selected which cell would become a red block. These images were saved as JPEG files, and presented in PsychoPy (Peirce, 2009) version 1.75 as part of the visual tasks described below.

Auditory tasks. A list of frequently used (above 2200 as reported by the HAL study) monosyllabic nouns was retrieved from the Washington University in Saint Louis, English Lexicon Project Website (<http://elexicon.wustl.edu/query13/query13.asp>). These were then grouped into semantically related sets of three to six words. Using an off-white PowerPoint

slide, these sets of words were typed in black, 60pt, Calibri font – centered both vertically and horizontally. These images were saved as JPEG files, and presented in PsychoPy (Peirce, 2009) version 1.75 as part of the auditory tasks described below.

I designed eight computer-based tasks - one auditory and one visual, for each of the four sub-skills - Immediate Recall, Sequencing, SoI, and Manipulation. These tasks are specifically designed to be characteristically similar within modality, and parallel within sub-skills across the two modalities. Each task has different levels of difficulty, ranging from three to six stimuli in length (blocks or words for visual and auditory, respectively). There are ten trials at each of these difficulty levels, resulting in a total of forty trials for each task. For each of the eight novel tasks, response time and accuracy were recorded. The goal of these tasks was to tease apart the modality from a participant's ability in each sub-skill.

Immediate recall – visual task. In this task (see Appendix A.1), a participant is shown a screen with small, equally-sized, squares spaced out in a seemingly random pattern. After viewing a fixation point, participants are shown a choice screen split into 3 sectors, each one of which showing a different pattern of squares, only one of which exactly replicating the first screen. Participants are asked to identify the exact replication of what they were shown.

Immediate recall – auditory task. This task (Appendix A.2) starts with a screen containing a list of words, followed by a fixation screen. The choice

screen is split into 3 sectors, each one of which containing a list of words and only one replicating the original list – the participant is asked to choose which is the replication.

Sequencing – visual task. This task (Appendix A.3) uses a similar initial cue screen as the Visual Immediate Recall task, but instead of a static presentation of the pattern, each square appears sequentially. Following a fixation point, the choice screen is split into 3 sectors, each with the same squares in the same correct places, but with different numbers labeling the squares and only one simulating the original sequence – asking the participant to identify the correct sequence.

Sequencing – auditory task. This task (Appendix A.4) uses a similar list of words as the Auditory Immediate Recall task, but instead of being presented as a static list, the words appear one at a time at the center of the screen, each disappearing before the next appears. After a fixation screen, the choice screen is split into 3 sectors, each of which has the same list of correct words, but presents them in a different order – the participant is asked to choose which is the correct order.

SoI – visual task. This task (Appendix A.5) uses a similar initial cue screen as the Visual Immediate Recall task, but adds a cognitive distractor task between introduction of the stimuli and recall. After being shown a fixation point, participants are shown three different directional arrows (in random order) and asked to press the corresponding key on the keyboard as fast as they can. After

this distractor, they are shown a screen split into 3 sectors, each one of which showing a different pattern of squares, only one of which exactly replicating the first screen – asking the participant to identify the replication.

SoI – auditory task. This task (Appendix A.6) uses a similar list of words as the Auditory Immediate Recall task, but adds the same cognitive distractor task as the Visual SoI task. After this distractor, they are shown a screen split into 3 sectors, each one of which contains a list of words and only one replicating the original list – the participant is asked to choose which is the replication.

Manipulation – visual task. This task (Appendix A.7) uses a similar initial cue screen as the Visual Immediate Recall task, but instead of a single color, the squares are some combination of black, blue and red. Following a fixation point, the choice screen asks for the sum of the blocks of two of those colors (the participant does not know which two colors will be asked for), and 3 numbers will be shown below the question – asking the participant to identify the correct sum.

Manipulation – auditory task. This task (Appendix A.8) uses a similar list of words as the Auditory Immediate Recall task, but instead of being presented as a static list, the words appear one at a time at the center of the screen, each disappearing before the next appears. After a fixation screen, the choice screen asks for the total number of syllables in the words that were shown, and 3 numbers

are shown below the question – the participant is asked to choose which is the correct total.

Participants

There were 60 participants recruited through flyers posted around Harvard University and the surrounding community (see Appendix B). Of these participants, the majority was female ($n = 41$) and native English speakers ($n = 49$) – all were fluent in English. Participants were recruited in two age classifications – age 18 to 29 ($n = 39$) and age 30 to 45 ($n = 21$). None of the participants had been diagnosed with either a language-based disability or a visual learning disability. All participants were right handed. All testing protocols were carried out in accordance with The Harvard University Committee on the Use of Human Subjects approval of this study – IRB# F23550-101.

Procedures

The order that the tests were administered was counter-balanced across participants (see Table 1). Half of the participants took all four sub-skills (Immediate Recall, Sequencing, SoI, and Manipulation) of one modality (auditory or visual), before taking all four sub-skills of the other modality. The other half of participants took both modalities of each sub-skill before moving on to the next sub-skill. Within each of these two groups, half of the participants took the auditory tasks before the visual, and the other half took the visual first.

Participants were evenly dispersed by gender and age classification between these four conditions. Additionally, participants completed a motor control task as well as standardized auditory and visual working memory tasks.

Table 1: The four participant conditions regarding order of task administration

	Grouped by Modality	Grouped by Sub-Skill
Auditory First	1. Auditory Immediate recall	1. Auditory Immediate recall
	2. Auditory SoI	2. Visual Immediate recall
	3. Auditory Sequencing	3. Auditory SoI
	4. Auditory Manipulation	4. Visual SoI
	5. Visual Immediate recall	5. Auditory Sequencing
	6. Visual SoI	6. Visual Sequencing
	7. Visual Sequencing	7. Auditory Manipulation
	8. Visual Manipulation	8. Visual Manipulation
Visual First	1. Visual Immediate recall	1. Visual Immediate recall
	2. Visual SoI	2. Auditory Immediate recall
	3. Visual Sequencing	3. Visual SoI
	4. Visual Manipulation	4. Auditory SoI
	5. Auditory Immediate recall	5. Visual Sequencing
	6. Auditory SoI	6. Auditory Sequencing
	7. Auditory Sequencing	7. Visual Manipulation
	8. Auditory Manipulation	8. Auditory Manipulation

Early in the study, a participant's comments about their performance on the Manipulation tasks raised doubt regarding the use of the task. From that point on, after administration of all tasks, each participant was asked to describe the strategy used on the manipulation tasks. The vast majority of participants were quite similar in their strategies. When participants were shown the multi-colored blocks in the Visual Manipulation task, they typically recited to themselves the number of blocks in each color – for example, “Three black, one red, one blue”. They would

repeat this to themselves until the choice screen asked for them to add two of the numbers. This is in contrast to the skill that the task was meant to measure – for participants to hold the mental image of the blocks in their mind and then count and add the blocks of the identified colors. In essence, most participants turned the Visual Manipulation task into an Auditory Manipulation task.

During the Auditory Manipulation task, participants were shown multiple words (one at a time) and then asked to add the total number of syllables. The task meant to measure their ability to hold the words in memory and then count the number of syllables. Instead, most participants just kept a running count of syllables as the words flashed on the screen – some participants actually used their fingers to do this. This turned the Auditory Manipulation task into a non-working memory task altogether. Considering the strategies used by participants, I made the decision to not include any of the data from the two Manipulation tasks in subsequent analysis.

Statistical Analysis

Data were analyzed using Stata 12 (StataCorp, 2011). Mean reaction times were calculated for each task using times for correct trials only. Data were screened for outliers by examining each participant by block within each task to determine if reaction times were more than 3 standard deviations below or above

the participant's mean reaction time. No reaction time outliers on correct trials were found.

Two-tailed t-tests comparing mean reaction times of each task by gender indicated that males and females did not differ on any of the six tasks (t-value from -1.50 to 0.77, Satterthwaite's DF from 28.17 to 34.92, p-value from 0.97 to 0.14). Young participants were expected to respond faster than their slightly older peers, and one-tailed t-tests comparing mean reaction times of each task by age revealed that younger participants displayed mean reaction times that were significantly faster than slightly older participants in all tasks except auditory recall. In spite of this absolute difference in reaction times, the relative correlations among tasks did not differ between young and old participant groups ($t=-1.27$, Satterthwaite's DF = 22.13, $p=0.216$). I therefore used pairwise correlations to describe the associations between the unique pairs of tasks collapsing the two age groups.

Pairwise correlations were calculated for the mean reaction times for each unique pair of tasks, resulting in nine pairs of pairwise correlations: 3 for the pairs of auditory modality tasks, 3 for the pairs of visual modality tasks, and 3 for the task types (i.e. Immediate Recall, SoI, and Sequencing) across modalities. Aligned with Cumming (2014), I used Confidence Intervals (CI) from the Fisher correlations in reporting the correlations, rather than p-values to evaluate whether

correlations within modalities differed significantly from correlations across modalities.

Results

All correlations between tasks can be seen in Table 2. While the strength of correlations vary, none of the 95% CIs includes zero – a finding that there are true associations between each of the tasks. As expected, the tasks within each modality (auditory and visual) have strong correlations to one another. The correlations between auditory tasks (Auditory Sequencing, Auditory SoI, and Auditory Immediate Recall) can be found in the upper left-hand section of Table 2, as well as the left side of Figures 3-5. These correlations range from .772 to .806, and are considered strong correlations. The correlations between visual tasks (Visual Sequencing, Visual SoI, and Visual Immediate Recall) can be found in the lower right-hand section of Table 2, as well as the right side of Figures 3 – 5. These correlations range from .602 to .728, and are considered strong correlations.

In order to explore the hypothesized sub-skills, I also examined inter-modality correlations, which can be found in the lower left-hand section of Table 2. The correlation for the sequencing sub-skill (Auditory Sequencing and Visual Sequencing) is a very strong correlation of .709 (95% CI .556 - .816). The correlation for the SoI sub-skill (Auditory SoI and Visual SoI) is .546 (95% CI .339 - .703), a moderately strong correlation. The correlation for the immediate

recall sub-skill (Auditory Immediate Recall and Visual Immediate Recall) is also moderately strong at .553 (95% CI .346 - .709). The correlations for these three inter-modality sub-skills can also be found at the center of Figures 3 – 5.

Table 2: Correlations between working memory tasks

	1	2	3	4	5	6
1) Auditory Sequencing	--					
2) Auditory Suppression of Interference	.772 (.647 - .859)	--				
3) Auditory Immediate Recall	.785 (.663 - .866)	.806 (.694 - .880)	--			
4) Visual Sequencing	.709 (.556 - .816)	.620 (.435 - .755)	.643 (.464 - .771)	--		
5) Visual Suppression of Interference	.645 (.467 - .772)	.546 (.339 - .703)	.526 (.314 - .688)	.656 (.483 - .780)	--	
6) Visual Immediate Recall	.627 (.442 - .761)	.569 (.367 - .720)	.553 (.346 - .709)	.602 (.410 - .744)	.728 (.581 - .830)	--

Note: Numbers in parentheses represent 95% Confidence Intervals

Orange blocks are correlations between Auditory tasks

Green blocks are correlations between Visual tasks

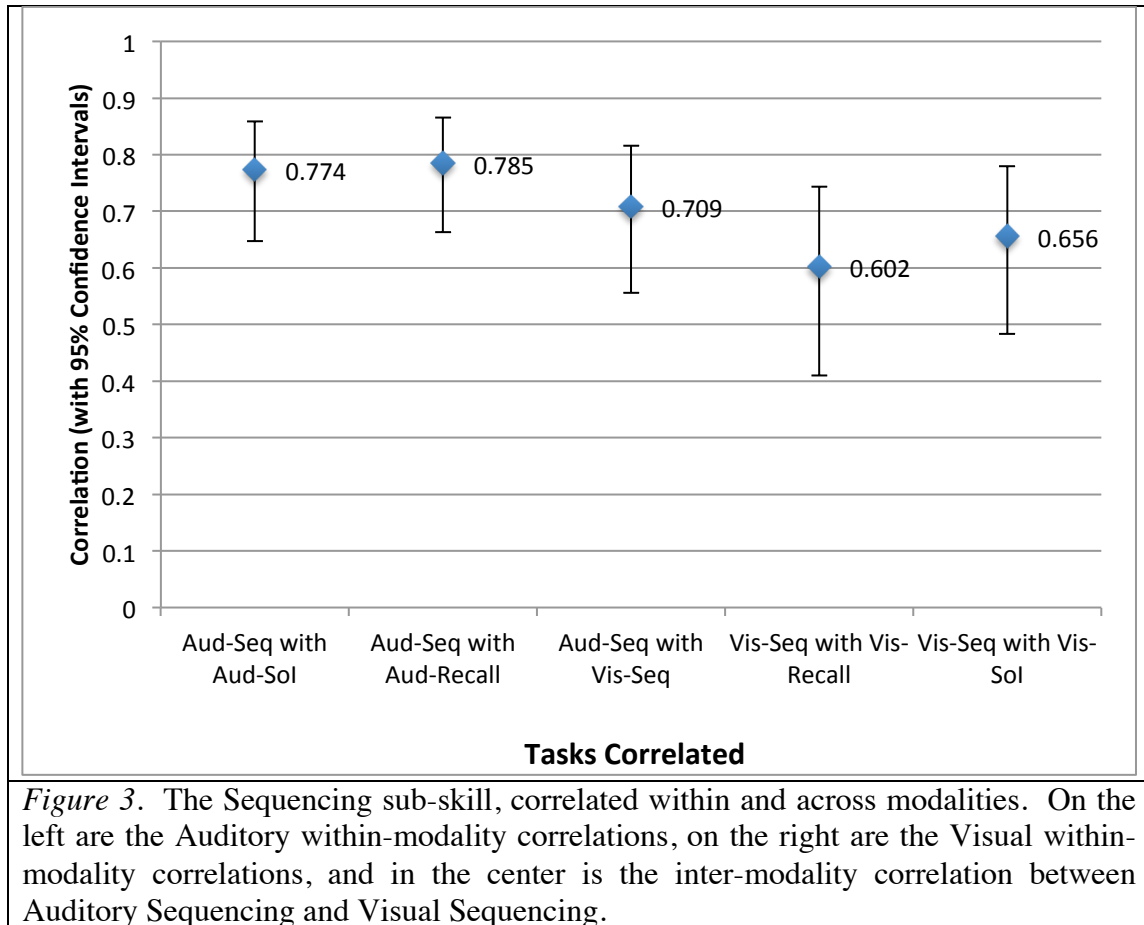
Blue blocks are inter-modality correlations within each sub-skill (Sequencing, SoI, and Immediate Recall)

Discussion

Commonly in current practice, students' (or research participants') results on the auditory tasks are grouped together to represent their "auditory working memory", and their results on the visual tasks are grouped to represent their "visual working memory". The purpose of this study was not to challenge whether these groupings are legitimate, but rather to demonstrate that there are other groupings that are equally legitimate and potentially provide valuable information and a new paradigm of understanding our students. For this reason, we focus on the correlation between Auditory and Visual tasks for each proposed sub-skill, and compare it to the correlation of tasks within each modality.

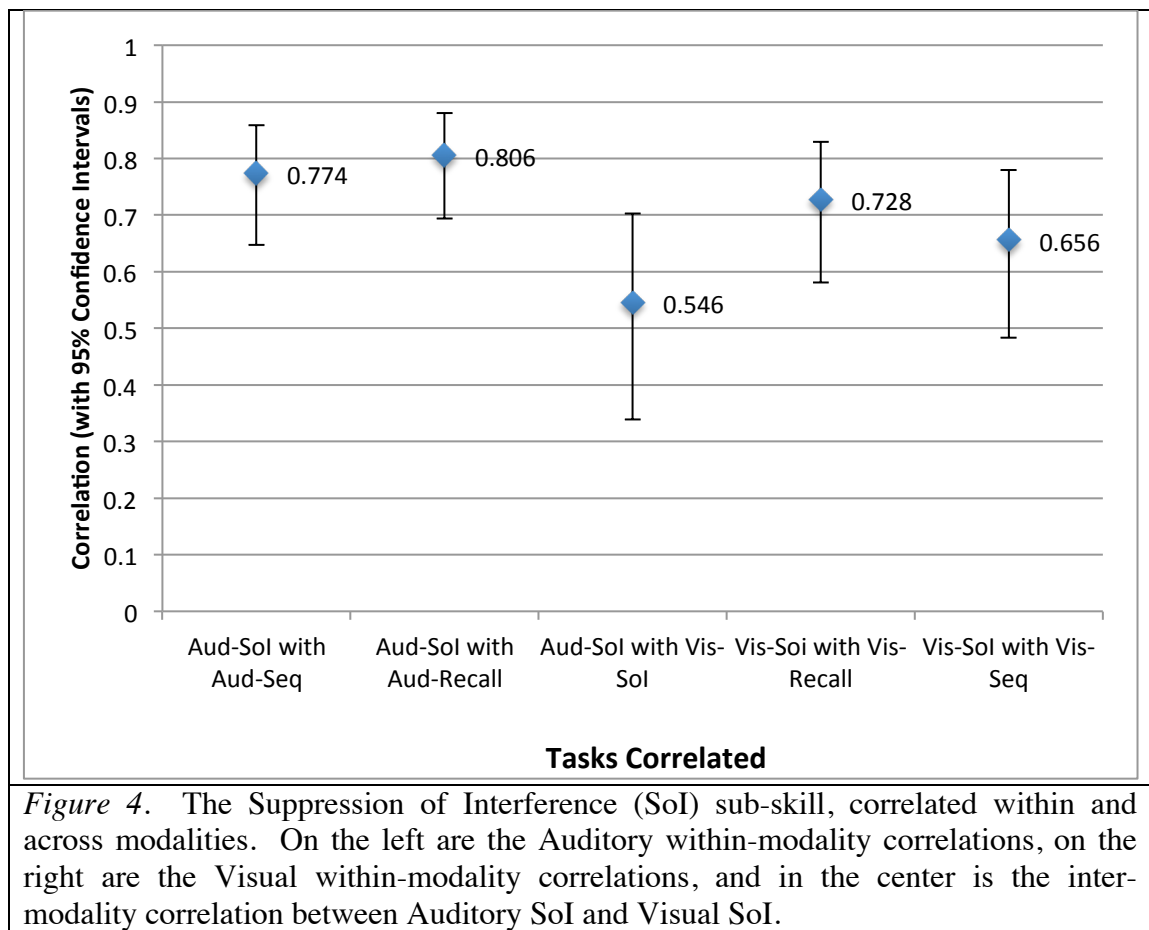
In addition to the expected strong correlations within each modality, we did find strong inter-modality correlations within each sub-skill. Figure 3 shows the correlations for the Sequencing sub-skill. The left two data points shows Auditory Sequencing's correlations with Auditory SoI and Auditory Immediate Recall, respectively. These represent the Auditory within-modality correlations. The center data point is the inter-modality correlation between Auditory Sequencing and Visual Sequencing. The right two data points show the Visual Sequencing correlations with Visual Immediate Recall and Visual SoI, respectively – representing the Visual within-modality correlations. As can be seen, the inter-modality correlation for Sequencing has a 95% CI that largely overlaps with the

95% CIs of all of the within-modality correlations – demonstrating that its correlation is not substantially different from the within-modality correlations.



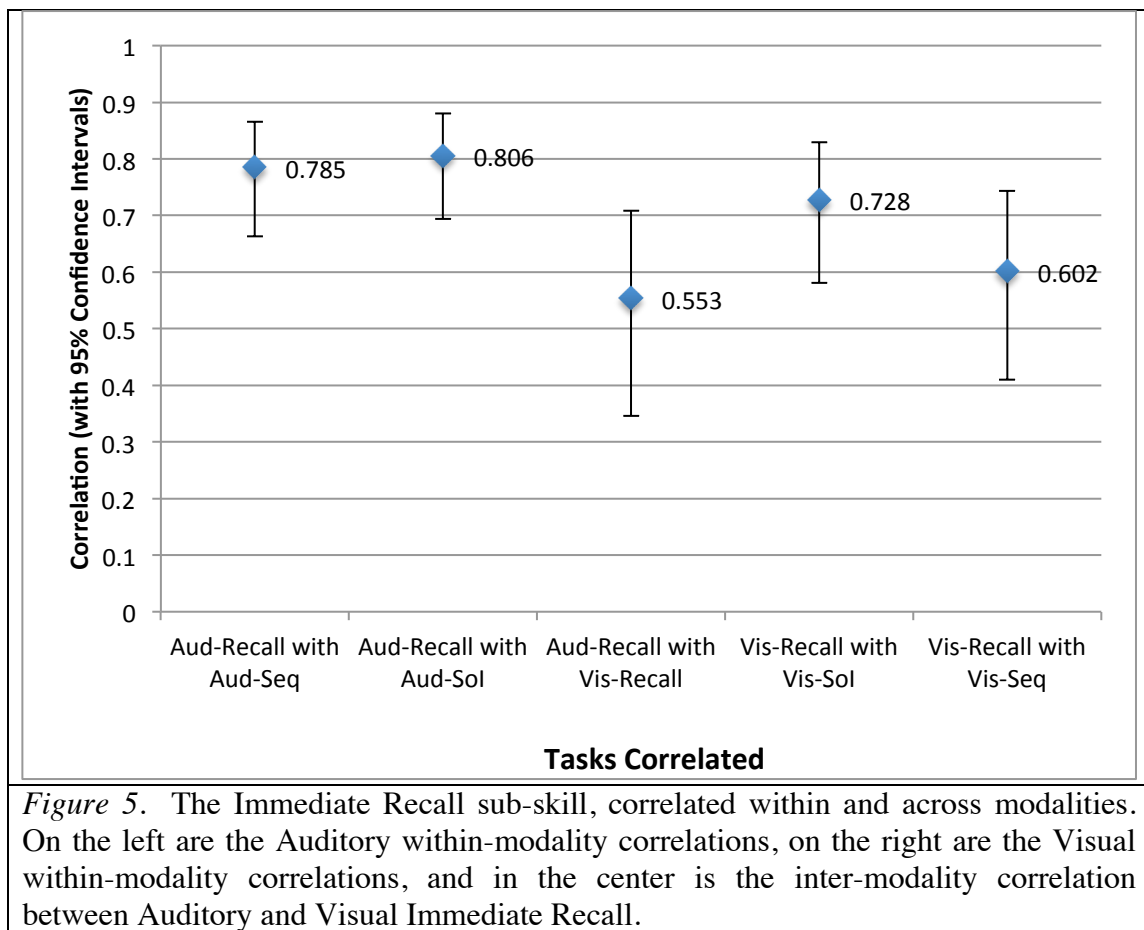
The correlations for the sub-skill of Sol are shown in Figure 4. The left two data points shows Auditory Sol's correlations with Auditory Sequencing and Auditory Immediate Recall, respectively. These represent the Auditory within-modality correlations. The center data point is the inter-modality correlation for Sol, between Auditory Sol and Visual Sol. The right two data points show the Visual Sol correlations with Visual Immediate Recall and Visual Sequencing,

respectively – representing the Visual within-modality correlations. The inter-modality correlation for SoI has a 95% CI that largely overlaps with the 95% CIs of the Visual within-modality correlations, but only slightly overlaps with the Auditory within-modality correlations. This shows that the inter-modality correlation for SoI is less than the Auditory within-modality, but similar as Visual within-modality correlations.



In Figure 5, the correlations are shown for the Immediate Recall sub-skill. The left two data points shows Auditory Immediate Recall correlations with

Auditory Sequencing and Auditory Suppression of Interference (SoI), respectively. These represent the Auditory within-modality correlations. The center data point is the inter-modality correlation for Immediate Recall, between Auditory Short-term Recall and Visual Short-term Recall. The right two data points show the Visual Immediate Recall correlations with Visual SoI and Visual Sequencing, respectively – representing the Visual within-modality correlations.



Similarly to the SoI correlations in Figure 4, the inter-modality correlation for Short-term Recall has a 95% CI that greatly overlaps with the 95% CIs of the

Visual within-modality correlations, but barely overlaps with the Auditory within-modality correlations. Like SoI, the inter-modality correlation for Immediate Recall is less than the Auditory within-modality, but comparable to Visual within-modality correlations.

This comparison of correlations is used in order to determine how appropriate it is to group tasks together. The findings do support the current practice of grouping tasks as Auditory and Visual – there are strong correlations among the tasks within each modality, especially the Auditory tasks. However, the findings also suggest that grouping tasks by sub-skill is similarly valid. Sequencing had equally strong correlations as either modality, and SoI and Immediate Recall each had correlations comparative to the Visual modality.

Implications

The implications of this research are important for both practitioners and researchers. This framework of sub-skills, rather than only modalities, can potentially change the paradigm of how practitioners interpret the results of special education assessments. Currently, if a student does substantially better on the Corsi block task than the reading span task, it would contribute to a belief that their Visual WM is superior to their Auditory WM. Potential classroom accommodations would include providing materials in visual formats such as directions given as pictures. This new framework, however, would understand the

discrepancy as a possible difference between the sub-skills of sequencing and SoI, and recommend that classroom accommodations utilize the student's strong sense of temporal order and help them avoid distractions in their environment. This shift of focus from modalities to skills could open alternative interventions for students in need.

Utilizing this framework of sub-skills could also potentially change how current and past research results are interpreted. For example, an important study found that students with specific language impairments have markedly lower scores on the auditory STM and WM, but not the visual STM or WM (Archibald & Gathercole, 2006). This finding could suggest interventions that would prioritize auditory over visual work. However, all of the visual WM tasks are SoI, while the auditory WM tasks are a mix of SoI and manipulation tasks. Is it possible that the real difference in performance is not about Auditory vs. Visual, but rather the sub-skill of manipulation? How could this change the interventions that would be considered "research-based"?

Conclusion

Working memory is too important for researchers and practitioners to use simplistic notions and broad categories. Our current reliance on the 4-part model of Auditory and Visual STM and WM may hide important differences between skills and deficits of students and patients. Findings in a variety of studies have shown that sequencing may be a skill unto itself, and that there is likely a

difference between the skill of handling distractors and that of mentally manipulating information.

This study sought to investigate the relationship between performances on different working memory tasks, as part of substantiating a novel framework for working memory assessments. Within each of the two typical modalities (Auditory and Visual), the proposed framework posited four sub-skills – Immediate Recall, Sequencing, Suppression of Interference, and Manipulation. I designed eight computer-based tasks – one auditory and one visual, for each of these four sub-skills – and examined correlations of response times between tasks. I found the anticipated strong correlations between tasks within a single modality (ie. Auditory Sequencing and Auditory Immediate Recall), confirming the existing paradigm of working memory as modality-related.

I hypothesized that there would also be strong correlations between tasks of the same sub-skill (ie. Auditory Sequencing and Visual Sequencing), supporting the value of also focusing on the proposed inter-modality sub-skills. This was most clearly found for the sub-skill of Sequencing, but was also evident in the sub-skills of Immediate Recall and Suppression of Interference. By utilizing this framework of working memory sub-skills, researchers and practitioners can take the next step forward in our understanding of the important concept of working memory.

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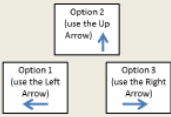
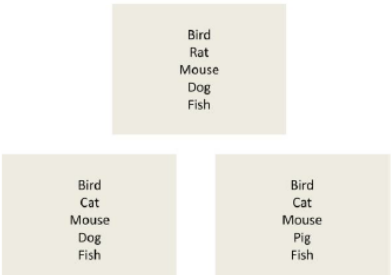
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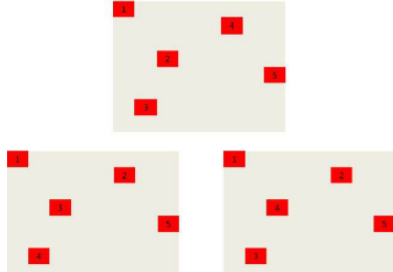
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Appendices

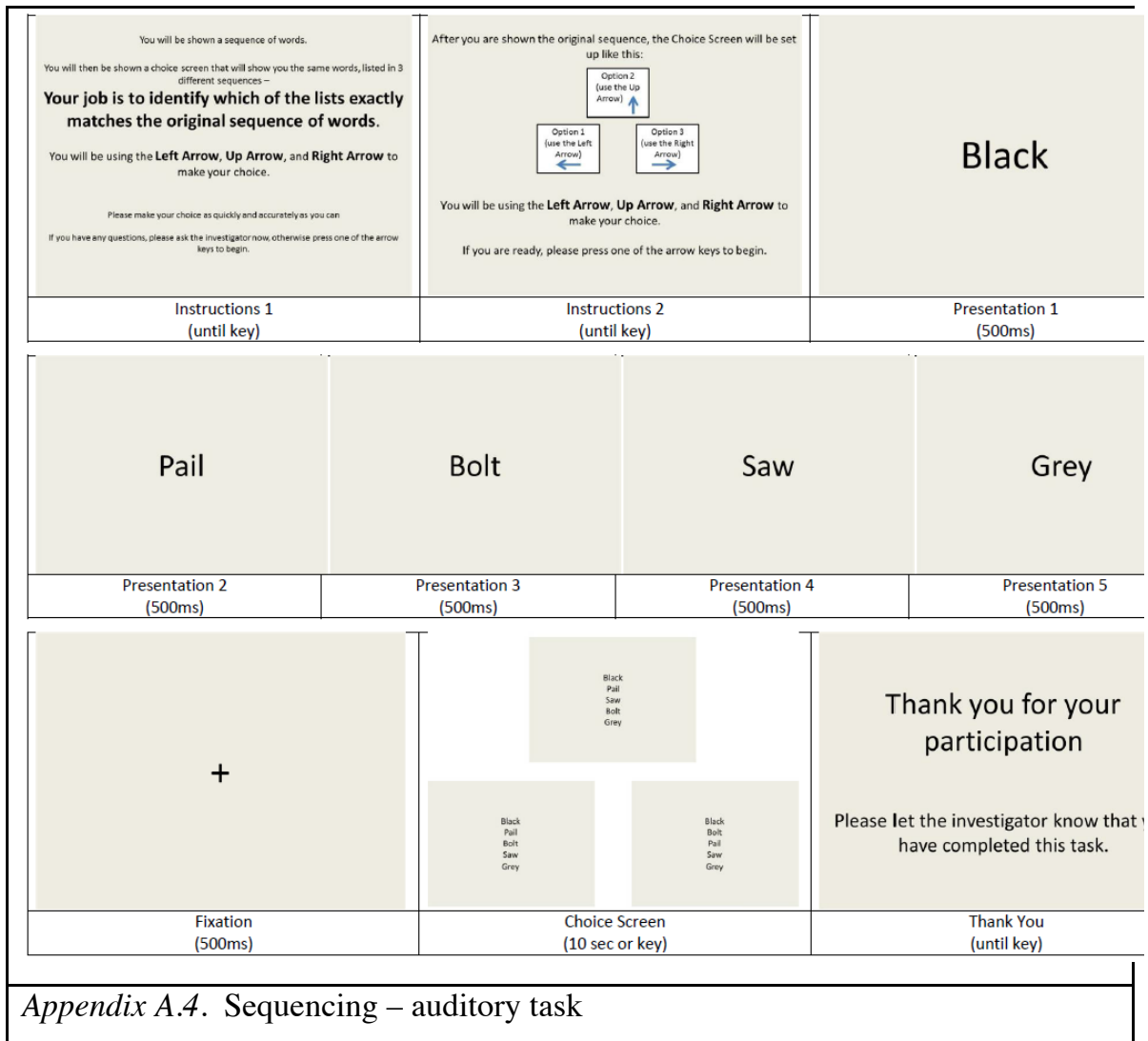
<p>You will be shown a pattern of blocks.</p> <p>You will then be shown a choice screen with 3 patterns of blocks –</p> <p>Your job is to identify which matches the original pattern.</p> <p>You will be using the Left Arrow, Up Arrow, and Right Arrow to make your choice.</p> <p>Please make your choice as quickly and accurately as you can</p> <p>If you have any questions, please ask the investigator now, otherwise press one of the arrow keys to begin.</p>	<p>After you are shown the original pattern, the Choice Screen will be set up like this:</p> <div><div>Option 2 (use the Up Arrow) ↑</div><div>Option 1 (use the Left Arrow) ←</div><div>Option 3 (use the Right Arrow) →</div></div> <p>You will be using the Left Arrow, Up Arrow, and Right Arrow to make your choice.</p> <p>If you are ready, please press one of the arrow keys to begin.</p>		<p>Instructions 1 (until key)</p>	<p>Instructions 2 (until key)</p>	<p>Presentation (500ms/block = 2.5 sec)</p>
		<p>Thank you for your participation</p> <p>Please let the investigator know that have completed this task.</p>	<p>Fixation (500ms)</p>	<p>Choice Screen (10 sec or key)</p>	<p>Thank You (until key)</p>
<p>Appendix A.1. Immediate recall – Visual task</p>					

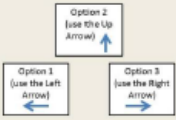




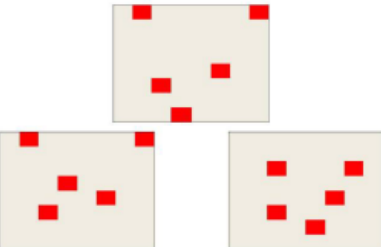
<p>You will be shown a list of words.</p> <p>You will then be shown a choice screen with 3 different lists of words – Your job is to identify which matches the original list.</p> <p>You will be using the Left Arrow, Up Arrow, and Right Arrow to make your choice.</p> <p>Please make your choice as quickly and accurately as you can</p> <p>If you have any questions, please ask the investigator now, otherwise press one of the arrow keys to begin.</p>	<p>After you are shown the original list, the Choice Screen will be set up like this:</p>  <p>You will be using the Left Arrow, Up Arrow, and Right Arrow to make your choice.</p> <p>If you are ready, please press one of the arrow keys to begin.</p>	<p>Bird Cat Mouse Dog Fish</p>
<p>Instructions 1 (until key)</p>	<p>Instructions 2 (until key)</p>	<p>Presentation (500ms/block = 2.5 sec)</p>
<p>+</p>		<p>Thank you for your participation</p> <p>Please let the investigator know that you have completed this task.</p>
<p>Fixation (500ms)</p>	<p>Choice Screen (10 sec or key)</p>	<p>Thank You (until key)</p>
<p>Appendix A.2. Immediate recall – Auditory task</p>		

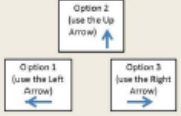



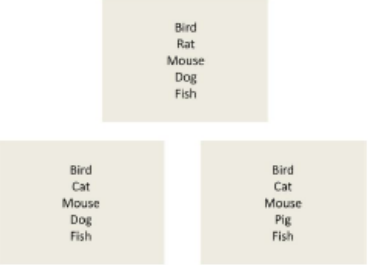
<p>You will be shown a sequence of blocks appearing on the screen.</p> <p>You will then be shown a choice screen that will show you the same pattern of blocks that are labeled with numbers to represent 3 different sequences –</p> <p>Your job is to identify which of the sequences matches the original sequence that the blocks appeared on the screen.</p> <p>You will be using the Left Arrow, Up Arrow, and Right Arrow to make your choice.</p> <p>Please make your choice as quickly and accurately as you can</p> <p>If you have any questions, please ask the investigator now, otherwise press one of the arrow keys to begin.</p>	<p>After you are shown the original sequence, the Choice Screen will be set up like this:</p> <div><div>Option 2 (use the Up Arrow) ↑</div><div>Option 1 (use the Left Arrow) ←</div><div>Option 3 (use the Right Arrow) →</div></div> <p>You will be using the Left Arrow, Up Arrow, and Right Arrow to make your choice.</p> <p>If you are ready, please press one of the arrow keys to begin.</p>		
Instructions 1 (until key)	Instructions 2 (until key)	Presentation 1 (500ms)	
 	  	  	   
Presentation 2 (500ms)	Presentation 3 (500ms)	Presentation 4 (500ms)	Presentation 5 (500ms)
		<p>Thank you for your participation</p> <p>Please let the investigator know that you have completed this task.</p>	
Fixation (500ms)	Choice Screen (10 sec or key)	Thank You (until key)	

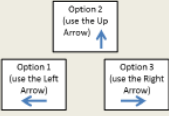
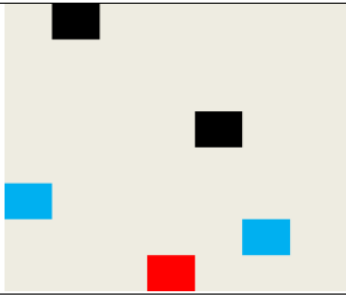

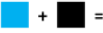
Appendix A.3. Sequencing – Visual task

Appendix A.3. Sequencing – Visual task



<p>1) You will be shown a pattern of blocks - Your job is to remember the pattern so that you can later identify it.</p> <p>2) Next, you will be shown several directional arrows in order to see how quickly you can press the corresponding arrow key.</p> <p>3) Lastly, you will be shown a choice screen with 3 different patterns of blocks - Please identify which matches the original pattern.</p> <p>You will be using the Left Arrow, Up Arrow, and Right Arrow to make your choice.</p> <p>Please make your choice as quickly and accurately as you can</p> <p>If you have any questions, please ask the investigator now, otherwise press one of the arrow keys to begin.</p>	<p>At the end, the Choice Screen will be set up like this:</p>  <p>You will be using the Left Arrow, Up Arrow, and Right Arrow to make your choice.</p> <p>If you are ready, please press one of the arrow keys to begin.</p>	
Instructions 1 (until key)	Instructions 2 (until key)	Presentation 1 (500ms)
<p>Press the appropriate arrow key as quickly and accurately as you can</p>		
Instructions 3 (1000ms)	Presentation 2 (500ms or until key)	Presentation 3 (500ms or until key)
	<p>Which of these matches the original pattern?</p> 	<p>Thank you for your participation</p> <p>Please let the investigator know that you have completed this task.</p>
Presentation 4 (500ms or until key)	Choice Screen (10 sec or key)	Thank You (until key)
Appendix A.5. Suppression of Interference (SoI) – Visual task		

<p>1) You will be shown a list of words - Your job is to remember the list so that you can later identify it.</p> <p>2) Next, you will be shown several directional arrows in order to see how quickly you can press the corresponding arrow key.</p> <p>3) Lastly, you will be shown a choice screen with 3 different lists of words – Please identify which matches the original list.</p> <p>You will be using the Left Arrow, Up Arrow, and Right Arrow to make your choice.</p> <p>Please make your choice as quickly and accurately as you can</p> <p>If you have any questions, please ask the investigator now, otherwise press one of the arrow keys to begin.</p>	<p>At the end, the Choice Screen will be set up like this:</p>  <p>You will be using the Left Arrow, Up Arrow, and Right Arrow to make your choice.</p> <p>If you are ready, please press one of the arrow keys to begin.</p>	<p>Bird Cat Mouse Dog Fish</p>
Instructions 1 (until key)	Instructions 2 (until key)	Presentation 1 (500ms)
<p>Press the appropriate arrow key as quickly and accurately as you can</p>		
Instructions 3 (1000ms)	Presentation 2 (500ms or until key)	Presentation 3 (500ms or until key)
		<p>Thank you for your participation</p> <p>Please let the investigator know that have completed this task.</p>
Presentation 4 (500ms or until key)	Choice Screen (10 sec or key)	Thank You (until key)
Appendix A.6. Suppression of Interference (SoI) – Auditory task		

<p>You will be shown a pattern of different colored blocks.</p> <p>You will then be shown a choice screen that will ask you a question about the number of blocks –</p> <p>Your job is to remember the number of blocks of each color, and then add or subtract them in order to answer the question.</p> <p>You will be using the Left Arrow, Up Arrow, and Right Arrow to make your choice.</p> <p>Please make your choice as quickly and accurately as you can.</p> <p>If you have any questions, please ask the investigator now, otherwise press one of the arrow keys to begin.</p>	<p>After you are shown the original pattern, the Choice Screen will be set up like this:</p>  <p>You will be using the Left Arrow, Up Arrow, and Right Arrow to make your choice.</p> <p>If you are ready, please press one of the arrow keys to begin.</p>	
<p>Instructions 1 (until key)</p>	<p>Instructions 2 (until key)</p>	<p>Presentation (500ms/block = 2.5 sec)</p>
	<p>The number of Blue blocks plus the number of Black blocks?</p>  <p>2 3 4</p>	<p>Thank you for your participation</p> <p>Please let the investigator know that you have completed this task.</p>
<p>Fixation (500ms)</p>	<p>Choice Screen (10 sec or key)</p>	<p>Thank You (until key)</p>
<p>Appendix A.7. Manipulation – Visual task</p>		

<p>You will be shown a list of words.</p> <p>You will then be shown a choice screen that will ask you a question about the number of syllables that were contained in those words –</p> <p>Your job is to remember the words, so that you can count the total number of syllables in those words.</p> <p>You will be using the Left Arrow, Up Arrow, and Right Arrow to make your choice.</p> <p>Please make your choice as quickly and accurately as you can</p> <p>If you have any questions, please ask the investigator now, otherwise press one of the arrow keys to begin.</p>	<p>After you are shown the original list, the Choice Screen will be set up like this:</p> <div><div>Option 2 (use the Up Arrow) ↑</div><div>Option 1 (use the Left Arrow) ←</div><div>Option 3 (use the Right Arrow) →</div></div> <p>You will be using the Left Arrow, Up Arrow, and Right Arrow to make your choice.</p> <p>If you are ready, please press one of the arrow keys to begin.</p>	<p>heart</p>	
Instructions 1 (until key)	Instructions 2 (until key)	Presentation 1 (500ms)	
intestines	kidney	pancreas	liver
Presentation 2 (500ms)	Presentation 3 (500ms)	Presentation 4 (500ms)	Presentation 5 (500ms)
+	<p>How many syllables were there in all of the words combined?</p> <p>9 11 13</p>	<p>Thank you for your participation</p> <p>Please let the investigator know that have completed this task.</p>	
Fixation (500ms)	Choice Screen (10 sec or key)	Thank You (until key)	

Appendix A.8. Manipulation – Auditory task



This study compares different types of memory using visual and language-based activities. We are looking for participants who are:

- ## What will you do?

- Contact us for more information!

Harvard.Working.Memory@gmail.com

This study is conducted by the Brain.Experience.Education lab at the Harvard Graduate School of Education under the supervision of Dr. Gigi Luk.